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Sustainability assessment of stormwater management systems and the importance of pollutants in runoff

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Key words

Ecotoxicity, environmental impacts, life cycle assessment, local treatment, priority pollutants, runoff

Summary

We develop a method to systematically include impacts caused by runoff discharge into the sustainability assessment of stormwater management systems. By defining priority pollutants and calculating mean concentrations, an average ecotoxicity impact per litre of runoff is calculated. Of all assessed substance groups present in runoff, metals cause the highest impacts. To integrate this method into holistic sustainability assessment, we assess the complete life cycle of a complex stormwater management. We show that runoff discharges have a high relative importance: The impacts exceed the combined impacts of implementation, maintenance and decommissioning of the stormwater management system.

Introduction

Innovative, local solutions to manage stormwater introduce green and blue elements to cities, and often allow reducing material and resource demands. Furthermore, where and how runoff is discharged changes, e.g., local, low-tech treatment options are used instead of central wastewater treatment plants. While economic costs and benefits are an inherent part in the planning process, sustainability assessment is often neglected, but has gained more attention in recent years.

Previous studies have aimed to assess the sustainability of single installations and catchment-wide stormwater management (SWM) systems, using life cycle assessment (LCA). The focus is usually on the impacts caused by the system itself, caused by non-location specific (global) emissions. Only some of the studies consider the local, on-site emissions of few selected pollutants through runoff discharge as a source of environmental impacts.

Material and methods

We developed a method to systematically integrate a wide range of pollutants into the sustainability system of SWM systems by carrying out the following steps:

1. Identification of priority pollutants based on comprehensive survey of potential stormwater pollutants identified in literature and by expert statements
2. Calculation of average concentrations in runoff based on the statistical analysis of a wide range of measurements found in literature
3. Translation into an average ecotoxicity impact per litre of runoff [comparative toxic unit (CTUe) per litre], using characterisation factors of the USEtox® model for emissions to freshwater and soil, and developed by Dong et al. (2016) for emissions of metals to seawater
4. Analysis of different treatment methods and their removal efficiency
5. Ecotoxicity assessment of different discharge and treatment scenarios

To evaluate the importance of these impacts caused by direct emissions, we analysed them in the context of a catchment-wide SWM system. We chose a plan designed to adapt an urban area to climate change, which incorporates a wide range of elements, e.g. pipes, channels, and green areas.

The environmental impacts of the SWM system were quantified using LCA, which is an internationally standardized method to evaluate products and systems. All relevant processes over the whole life cycle of the system were included in the modelling of an emission- and resource use inventory (Fig. 1). The ecotoxicity impacts caused by implementing, maintaining, and decommissioning the system are then compared to the impacts caused by discharge of runoff during the use stage.

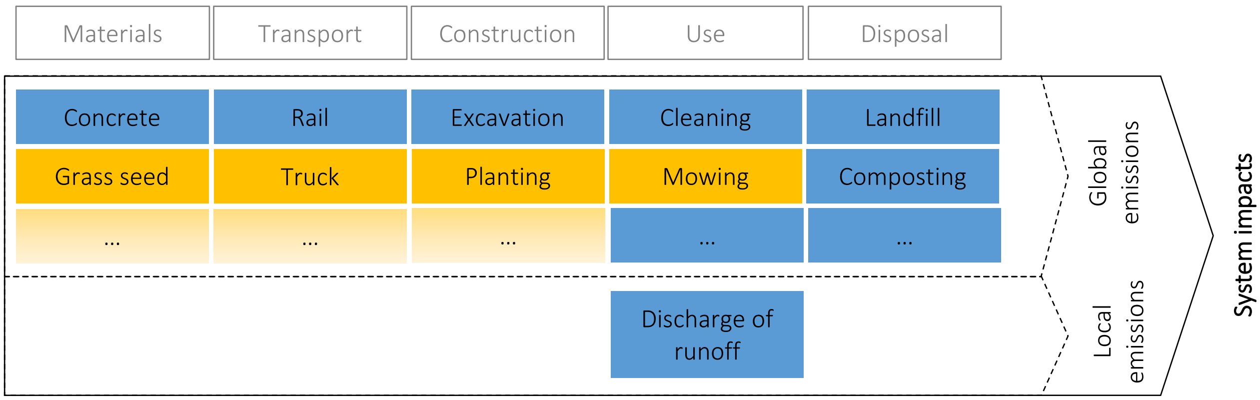

Figure 1. System boundaries

Results and discussion

Ecotoxicity impacts caused by local emission of pollutants in runoff

Both metals and organic compounds occurring in runoff are included in the inventory. Concentrations vary greatly depending on the area type, rain event, and other parameters. Since we are interested in average impacts, a mean concentration was calculated based on minimum, maximum, and average concentrations found in literature. The highest mean concentration for metals was calculated for zinc (716µg/l), and in nano-gram range for organic compounds.

Ecotoxicity impacts caused by pollutants depend on the environmental compartment to which they are emitted. Impacts caused by metals discharged to freshwater is one (two) order of magnitude higher than for discharges to soil (seawater). Impacts caused by organics are one order of magnitude higher for emissions to freshwater than for soil (Tab. 1). Characterisation factors for emissions of organics to seawater currently do not exist. Calculated impacts from emission to natural soil are probably overestimating the actual effects, since the characterisation factors used include erosion. As the time horizon of the SWM systems is limited and the topography is rather flat, erosion will not be a significant source of pollutants.

Table 1. Ecotoxicity impacts caused by runoff discharge

	Ecotoxicity impacts [CTUe] caused by emission of 1 litre of stormwater runoff to		
	freshwater	natural soil	seawater
Metals	1.24E+00	6.59E-01	7.98E-02
Organics	2.99E-02	8.80E-04	(no characterisation factors available)

Heavy metals are identified as the main driver for ecotoxicity impacts, with copper and zinc causing the highest impacts within this substance group. PAHs, dioxins, and pesticides are the substance groups with the highest impacts within the organic compounds (Figure 2).

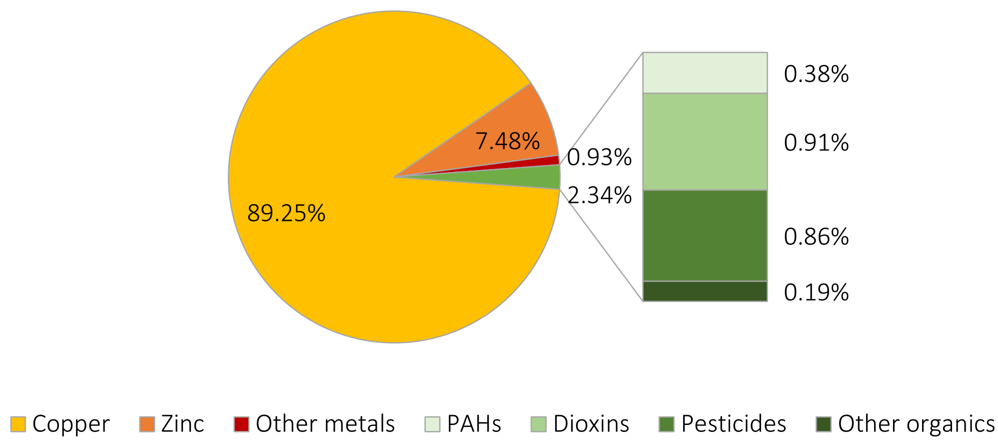

Figure 2. Relative contribution of pollutants to the total ecotoxicity impacts

Two different treatment options are evaluated based on removal efficiency values found in literature:

- Double porous filter: 80% for copper and zinc;
- Bioretention: 50% for copper, 70% for zinc, 40% for chromium, and 90% for lead.

No removal of other metals or organics was included, as no data was available. The impacts are reduced by 50% by treatment in a double porous filter (1.27CTUe/l to 0.64CTUe/l), and by 77% by bioretention (to 0.29CTUe/l).

Relative contribution of local emissions to the total system impacts

The assessment of a complete SWM system (Fig. 1) shows that ecotoxicity impacts stemming from global emissions of the SWM system are in the same order of magnitude as the impacts resulting from local emissions (14 mio. CTUe, and 20 mio. CTUe respectively). Runoff is only discharged during the use stage, which is by far the longest life cycle stage of the system. The resulting ecotoxicity impacts exceed the impacts of all other life cycle stages combined. Here, no treatment is considered, and by implementing appropriate structures, the local impacts could be reduced. At the same time, material extraction and construction processes for these structures would cause additional global emissions.

Conclusions

The assessment of ecotoxicty impacts resulting from SWM systems clearly shows the importance of including impacts resulting from discharges of runoff, and of considering adequate treatment options during the design phase. More detailed analysis of the environmental costs and benefits of treatment options is the subject of ongoing work, as well as sensitivity and uncertainty analysis.

Acknowledgements

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